NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

THE REDUCTION OF NONUSEFUL PRESSURE LOSSES ON

AIR-COOLED ENGINE CYLINDERS BY MEANS OF

IMPROVED FINNING AND BAFFLING

By M. J. Brevoort, U. T. Joyner, and George P. Wood

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A detailed analysis of the pressure drop that is required to cool a typically baffled radial engine shows that a total pressure drop of 58 pounds per square foot is necessary at sea level and 112 pounds per square foot is required at an altitude of 40,000 feet (assuming that the engine develops the same horsepower at both altitudes). A breakdown of these required pressure drops is given in the following table as percent of available pressure drop:

	Sea level (percent)	40,000 feet (percent)
Useful frictional pressure drop	6.6	15.8
Pressure drop due to increased momentum of air	4.7	32.2
Pressure drop at baffle exit	16.3	42.6
Percent of available drop required for cooling.	27.6	90.6

The fact that so large a percentage of the required pressure drop consists of a nonuseful pressure loss (76 percent at sea level and 83 percent at 40,000 feet) is a condition that merits attention. Means are proposed for reducing this nonuseful pressure loss. Note that at an altitude slightly in excess of 40,000 feet, conditions become critical and the elimination of nonuseful pressure losses becomes of vital importance.

The three principal causes of pressure loss on an air-cooled cylinder as listed on page 1 are defined as

1. ΔP_f pressure loss due to friction (beneficial)

2. ΔP_m pressure loss due to increase in momentum as air passes between the fins $= 2(q_2 - q_1)$ (nonbeneficial)

3. ΔP_e pressure loss at exit from fins $= Kq_2$ (non-beneficial). The positions at which q_1 and q_2 are taken are shown below.
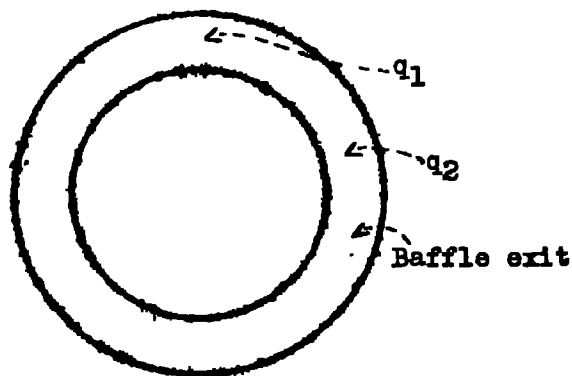
The arrangement for flow in pipes which is analogous to flow through a conventional baffle and finning combination is shown here.
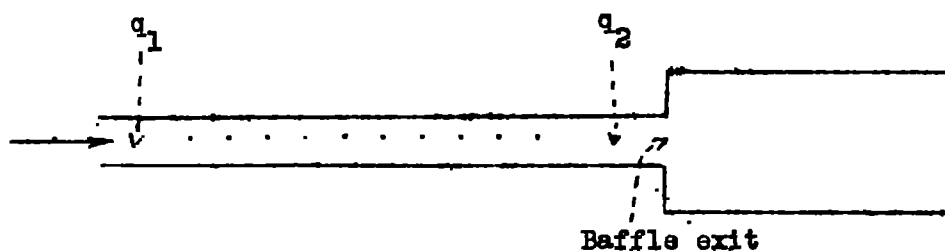
An efficiency factor E may be defined as the ratio of beneficial pressure loss to total pressure loss, as follows:

$$E = \frac{\Delta P_f}{\Delta P_f + \Delta P_m + \Delta P_e} = \frac{\Delta P_f}{\Delta P_f + (2+K)\,q_2 - 2q_1}$$

K has been determined from tests (reference 1) to be approximately 0.7 for model cylinders.

Because the pressure drop available at high altitudes is now a limiting factor on the maximum altitude at which a particular engine may operate satisfactorily, any means of increasing the pressure loss efficiency E will effec—

tively increase the pressure drop available for cooling and permit operation at a higher altitude.

In order to show what gains are possible over an existing engine type, calculations of the pressure drop required for cooling such a type at sea level and 40,000 feet altitude are given in table I.

TABLE I

	Sea level	40,000 feet
M, lb/sec	32.47	18.95
q_1, lb/ft²	43.96	55.51
q_2, lb/ft²	48.89	75.44
H_{S_1}, lb/ft² (a)	2345.12	487.12
ΔP_f, lb/ft²	13.93	19.64
ΔP_m, lb/ft²	9.86	39.86
ΔP_e, lb/ft²	34.22	52.80
ΔP_{total}	58.01	112.30

(a) H_{S_1} — static pressure at position 1 in fin.

The pressure loss efficiencies at these two altitudes are

$$E_{sea\ level} = \frac{13.93}{13.93 + 9.86 + 34.22} = 24\ percent$$

$$E_{40,000\ ft} = \frac{19.64}{19.64 + 39.86 + 52.80} = 17\ percent$$

There are at least three ways of increasing this efficiency:

1. The obvious solution of adding enough surface area so that the velocities required to cool, and hence q_1 and q_2, are very small and the nonbeneficial pressure losses become negligible. This solution is being extended as fast as manufacturing technique will permit.

2. By increasing the width of the fins gradually toward the rear of the cylinder as shown by analogy below.
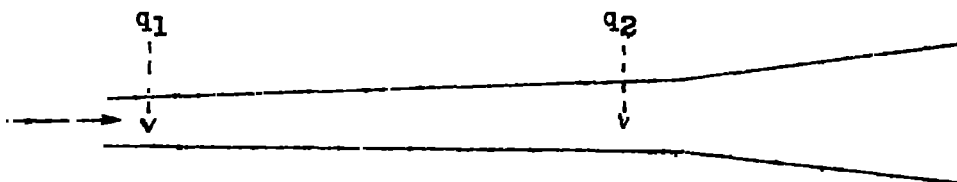
This solution would allow the air to expand to lower pressure without speeding up in passing through the fins, so that, if properly done, $q_2 = q_1$
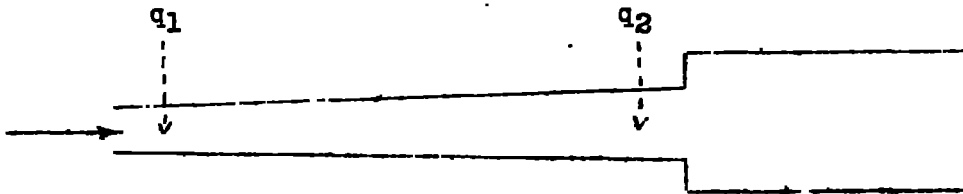
3. By improving exit conditions so that the factor K will be lower than 0.7. See analogy below.
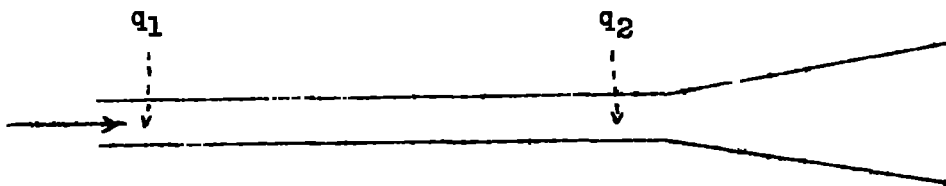
If both of these solutions are incorporated, the following analogy applies

By incorporating solution 2 th   fficiencies may be revised to be

$$E = \frac{\Delta P_f}{\Delta P_f + Kq_1}$$

$$E_{sea\ level} = \frac{13.93}{13.93 + 0.7(43.96)} = 31\ percent$$

$$E_{40,000\ ft} = \frac{19.64}{19.64 + 0.7(55.51)} = 33\ percent$$

If solution 3 alone is applied by reducing K from 0.7 to 0.3, the efficiencies are improved to

$$E_{sea\ level} = \frac{13.93}{13.93 + 2.3(48.89) - 2(43.96)} = 36\ percent$$

$$E_{40,000\ ft} = \frac{19.64}{19.64 + 2.3(75.44) - 2(55.51)} = 24\ percent$$

If solutions 2 and 3 are applied simultaneously, the efficiences are

$$E_{sea\ level} = \frac{13.93}{13.93 + 0.3(43.96)} = 51\ percent$$

$$E_{40,000\ ft} = \frac{19.64}{19.64 + 0.3(55.51)} = 54\ percent$$

The following table shows how many times the beneficial pressure loss may be increased for a given total pressure loss by successful application of solutions 2 and 3 given above.

	Sea level	40,000 feet
Original engine.	1.00	1.00
With solution 2 only . . .	1.29	1.73
With solution 3 only . . .	1.50	1.41
With solutions 2 and 3 . .	2.12	3.17

The improvement at sea level is important, but not vital, because sufficient pressure drop is available for cooling. However, at altitude the larger improvement possible is of tremendous importance, because cooling pressure loss is now a limiting factor on maximum altitude.

It is believed by the authors that these proposals should be investigated on a full-scale engine mock-up.

Langley Memorial Aeronautical Laboratory,
     National Advisory Committee for Aeronautics,
          Langley Field, Va., November 4, 1942.

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REFERENCE

1. Brevoort, M. J., and Joyner, U. T.: The Problem of
      Cooling an Air—Cooled Cylinder on an Aircraft
      Engine. NACA Rep. No. 719, 1941.